Cameras

Raul Queiroz Feitosa

Objective

This chapter describes the basics of the imaging process.

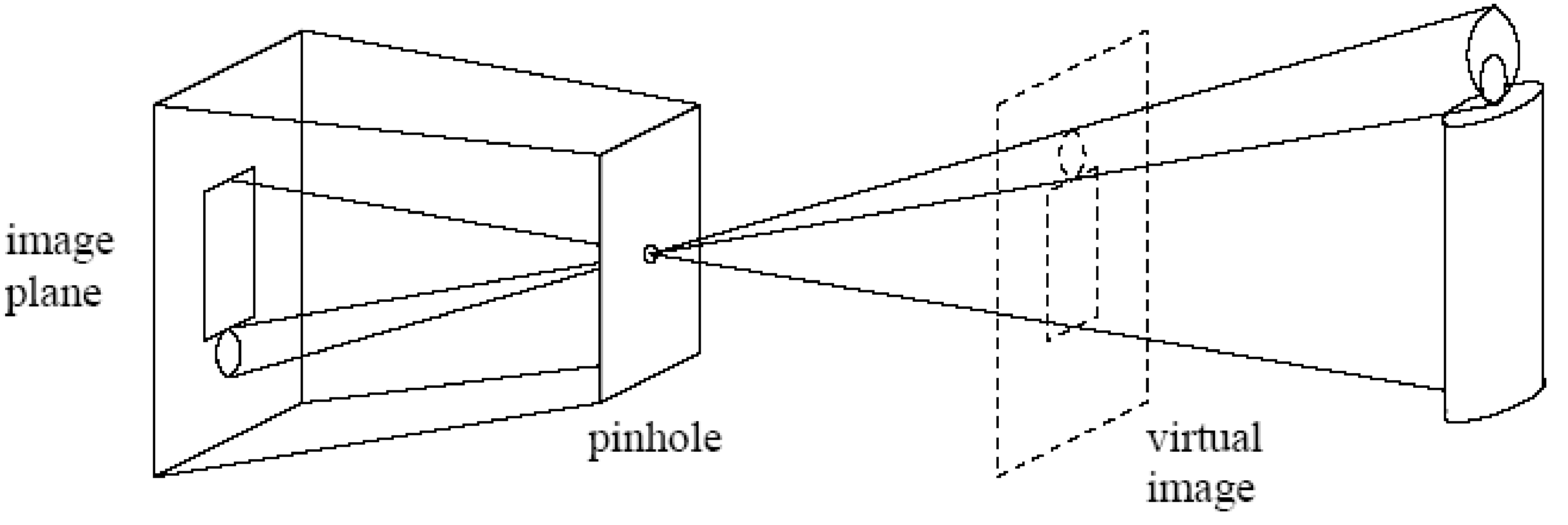
Cameras

Content:

- Perspective Projection
- Affine Projection
- Cameras with Lenses
- Aberrations
- Sensing

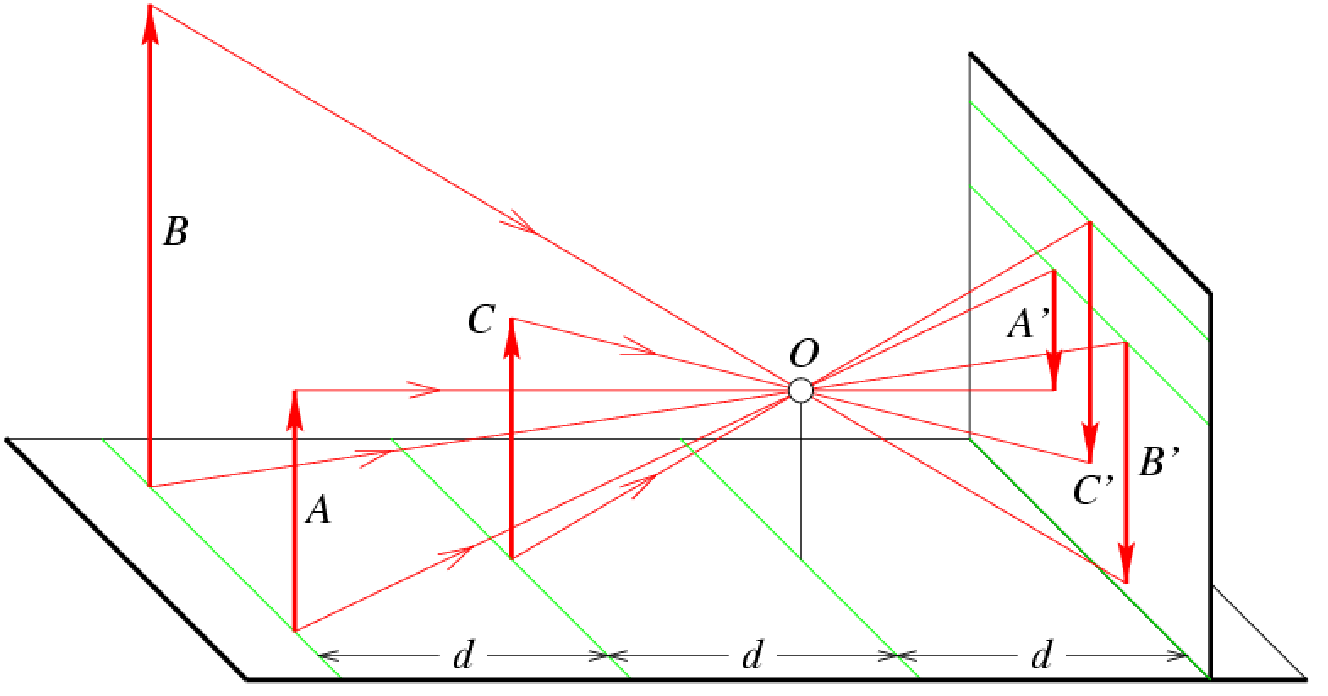
Perspective Projection

Pinhole imaging model



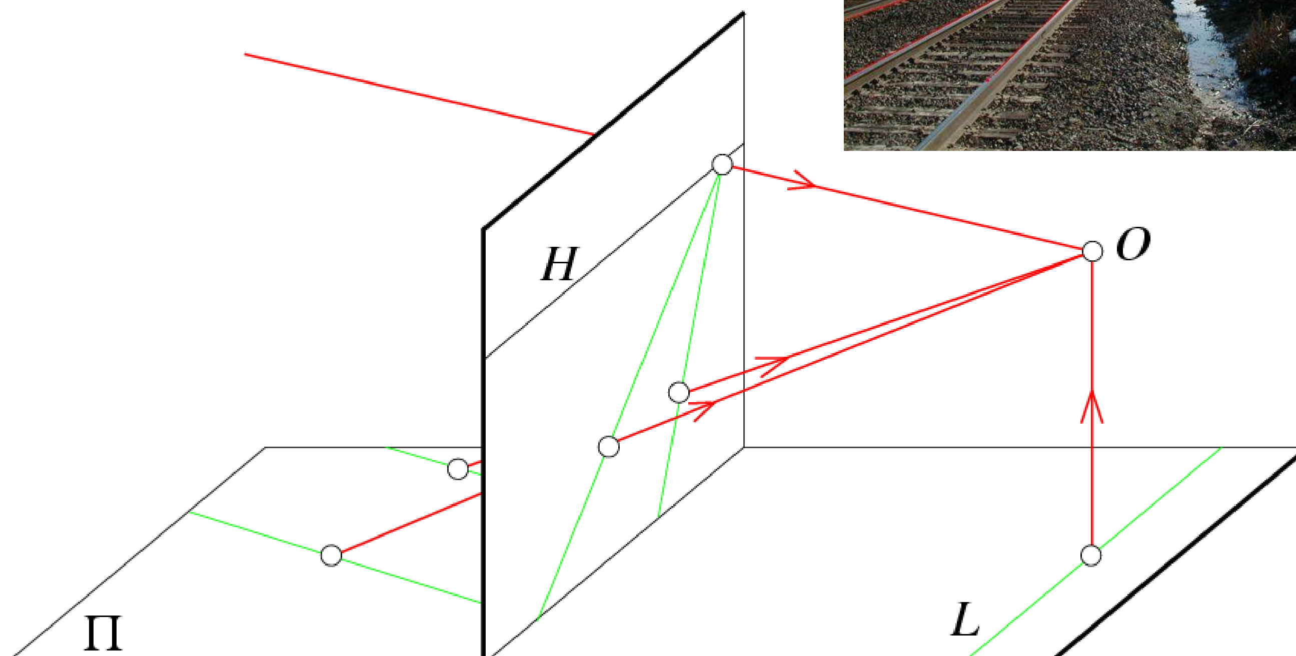
Perspective Projection

Distant objects appear smaller



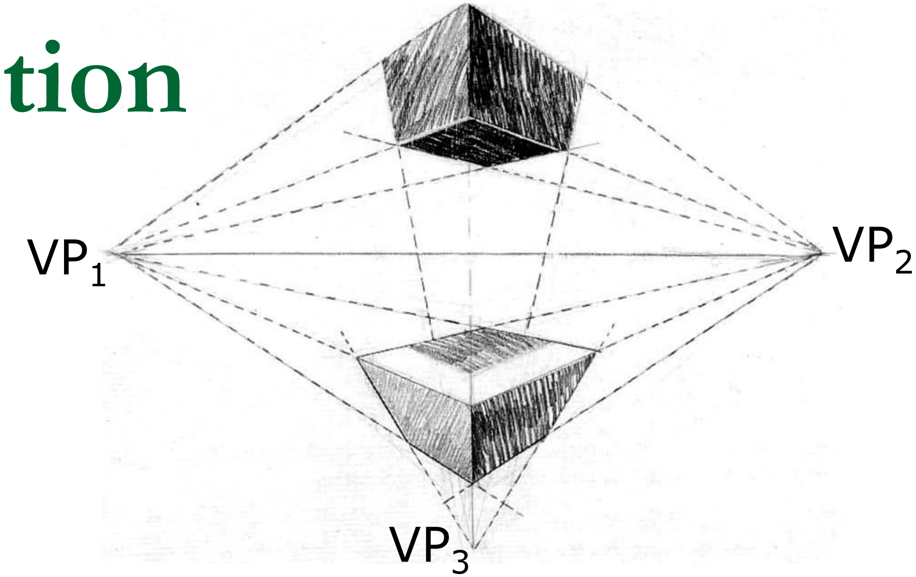
Perspective Projection

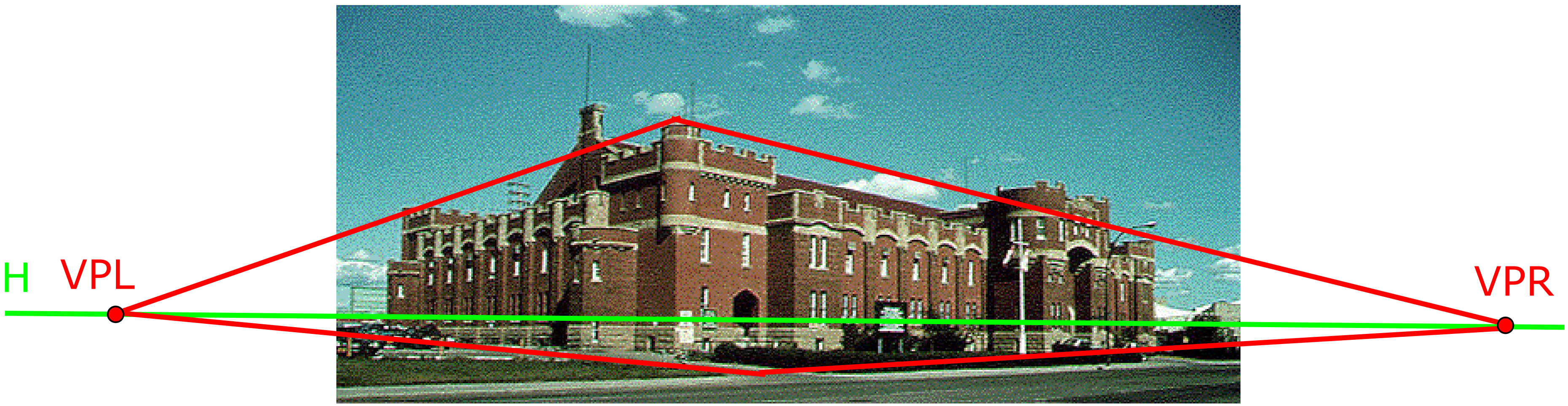
Parallel lines meet



Perspective Projection

Vanishing points

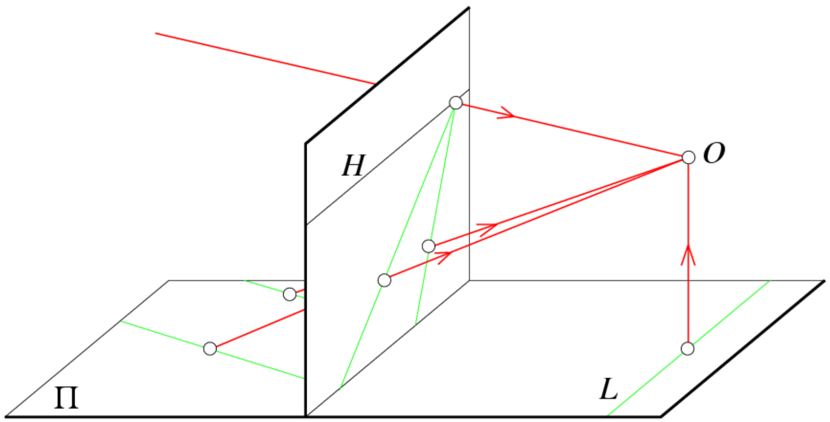




Perspective Projection

Geometric Properties

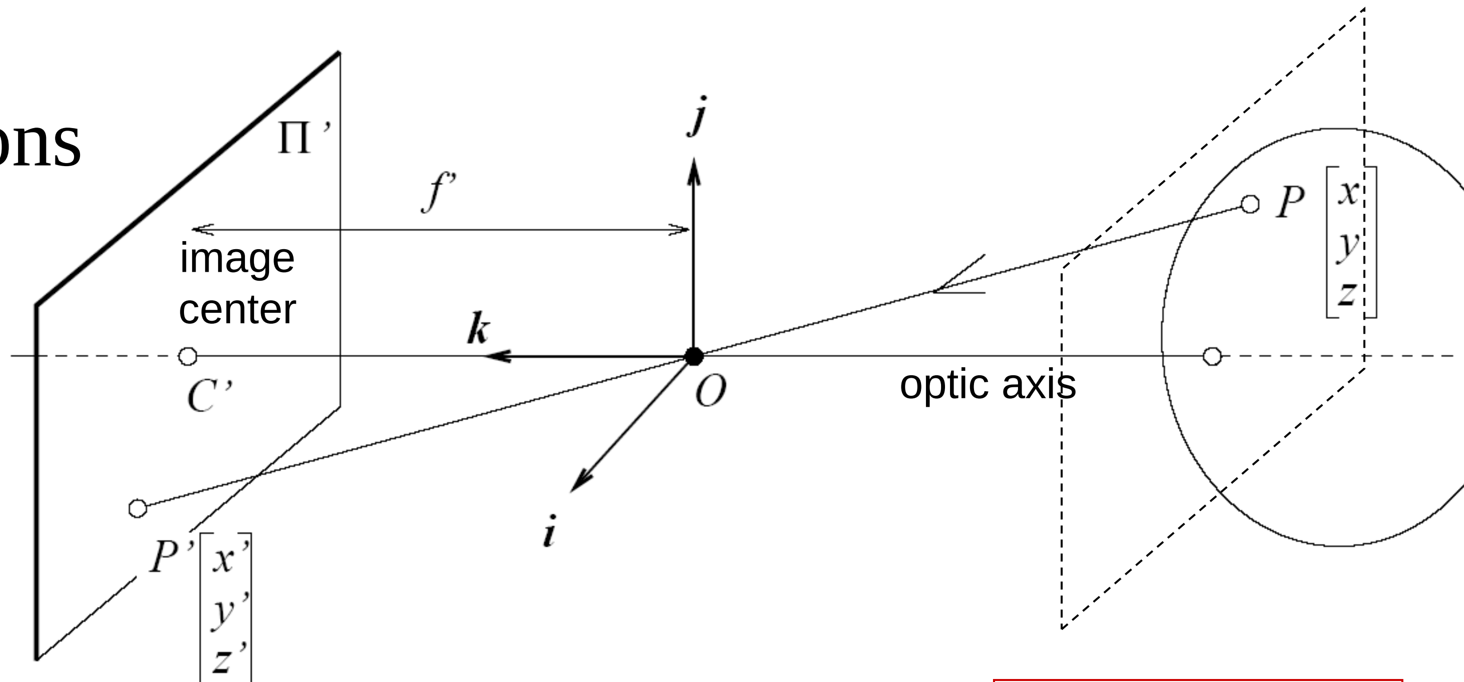
- Points go to points
- Lines go to lines
- Planes go to whole image or half-plane
- Polygons go to polygons



- Degenerated cases:
  - line through focal point yields point
  - plane through focal point yields line

Perspective Projection

Equations



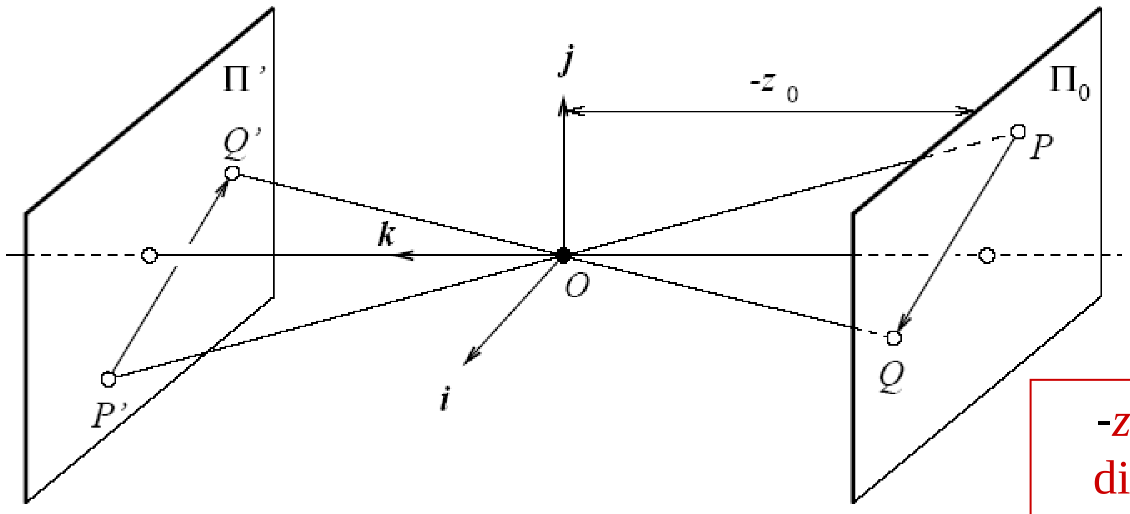
$$\begin{cases} x' = \lambda x \\ y' = \lambda y \\ f' = \lambda z \end{cases} \Rightarrow \lambda = \frac{x'}{x} = \frac{y'}{y} = \frac{f'}{z}$$

therefore

$$\boxed{\begin{cases} x' = f' \dfrac{x}{z} \\ y' = f' \dfrac{y}{z} \end{cases}}$$

Affine Projection

Weak-perspective: when the scene depth is small relative to the average distance to the camera



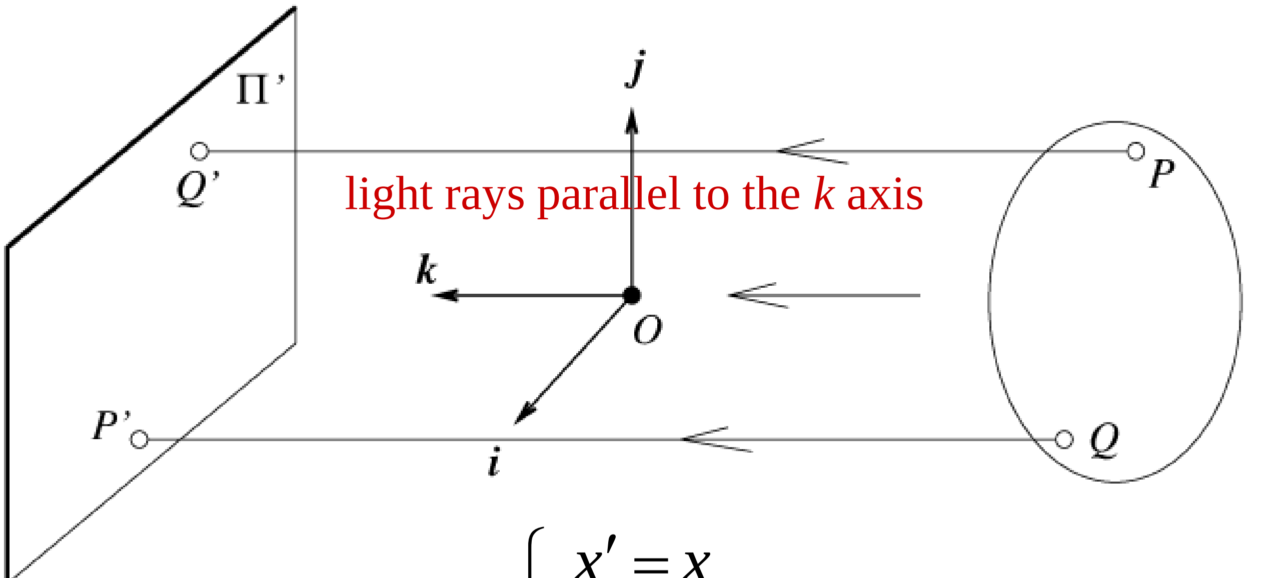
$$\begin{cases} x' = -m\,x \\ y' = -m\,y \end{cases}$$

$$m = -\frac{f'}{z_0}$$

$-z_0$ is the average distance from the objects to the optic center.

Affine Projection

Orthographic projection: camera at a roughly constant distance from the scene (*m=-1*)

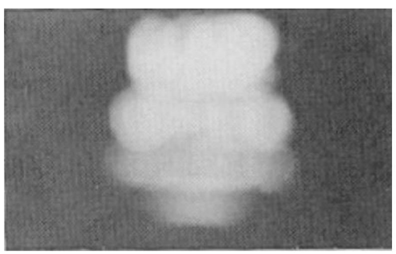


$$\begin{cases} x' = x \\ y' = y \end{cases}$$

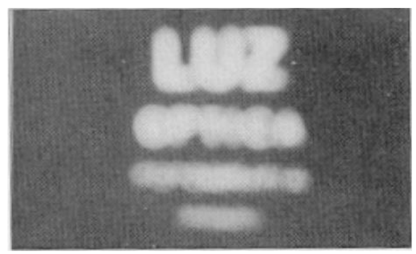
Camera with Lenses

Limits for pinhole cameras

1. The larger the hole the wider the light cone angle → blurred image
2. The smaller the hole the darker the image (longer exposition time)
3. The smaller the hole the stronger the diffraction effect → blurred image



2 mm



1 mm

0,6 mm

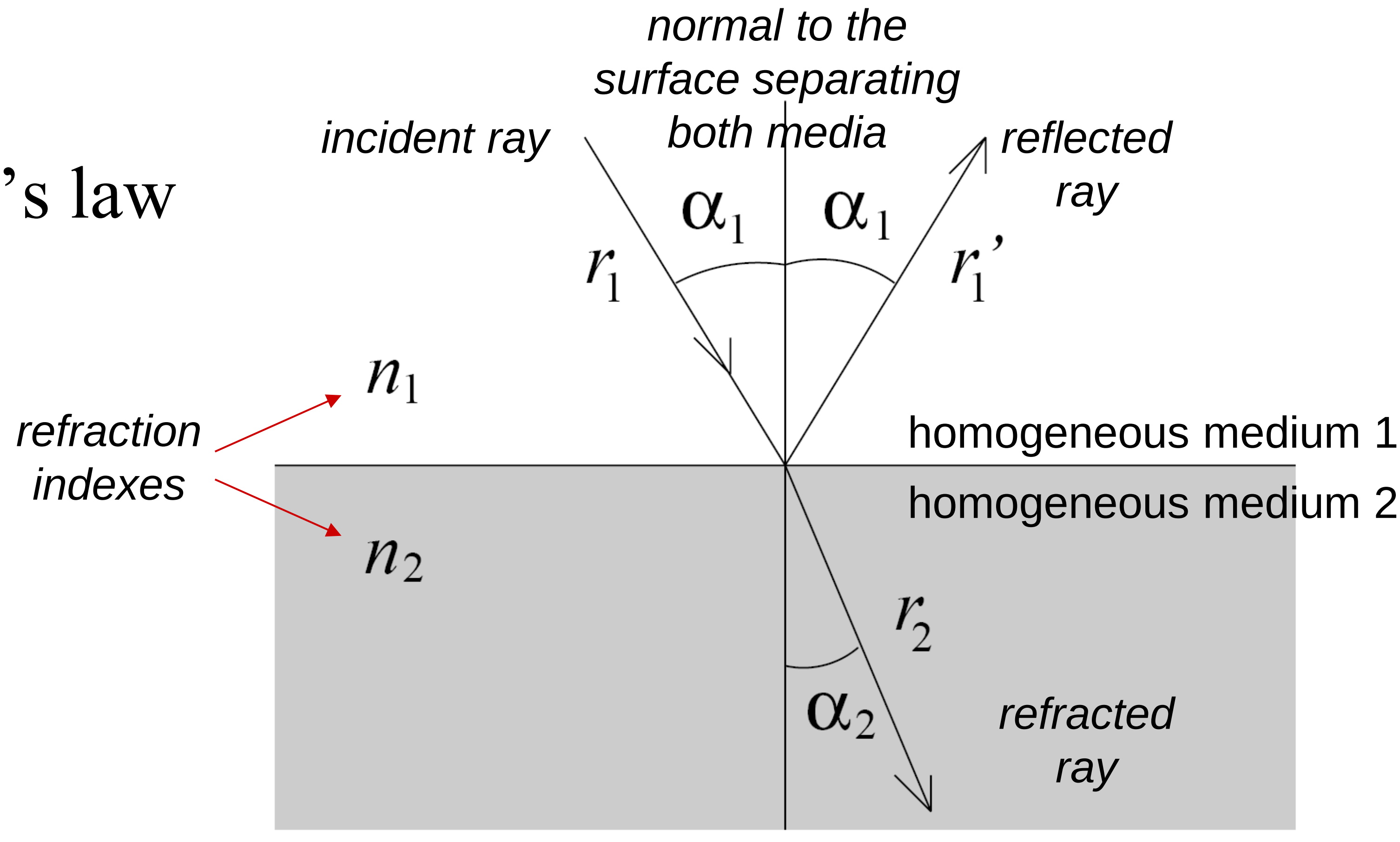
0,35 mm

0,15 mm

0,07 mm

Camera with Lenses

Snell's law



$$\boxed{n_1 \,\text{sen}\, \alpha_1 = n_2 \,\text{sen}\, \alpha_2}$$

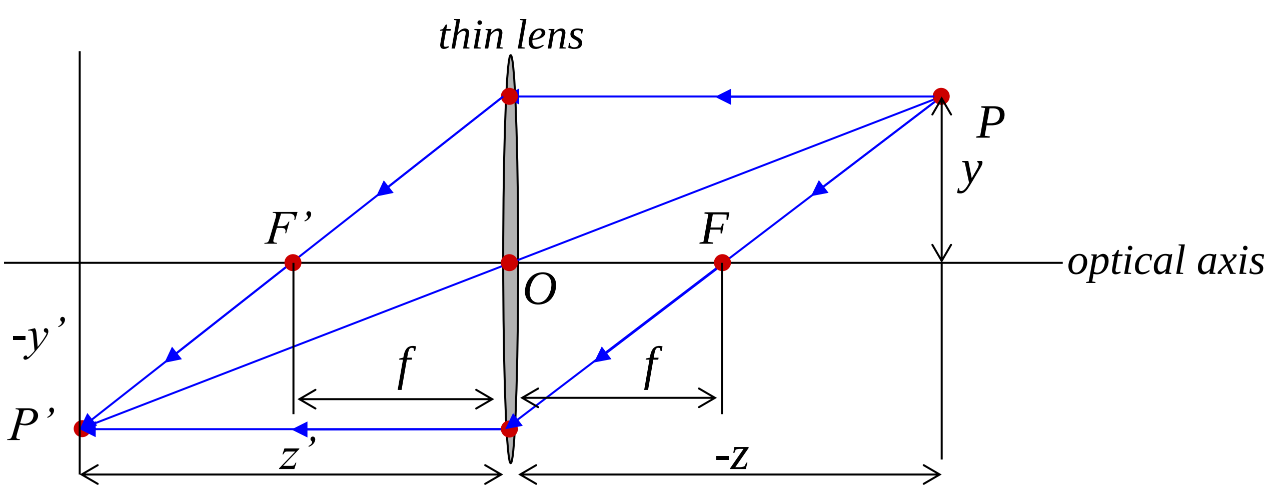
paraxial geometric optics

$$\boxed{n_1 \ \alpha_1 \approx n_2 \ \alpha_2}$$

Camera with Lenses

Thin Lenses

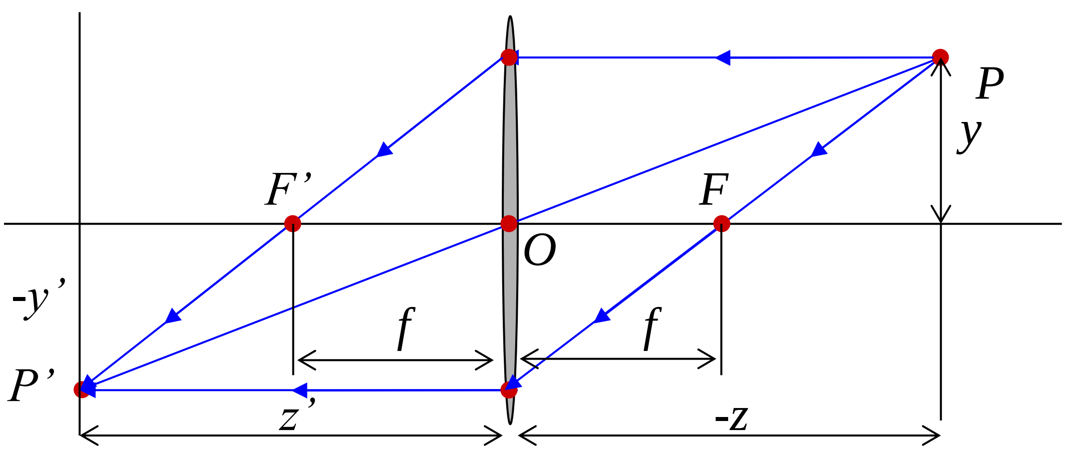
- Lenses are assumed to be rotationally symmetric about a straight line called *optical axis*.
- The ray entering a *thin lens* and refracted at its right boundary is immediately refracted again at the left boundary.



Camera with Lenses

Thin Lenses

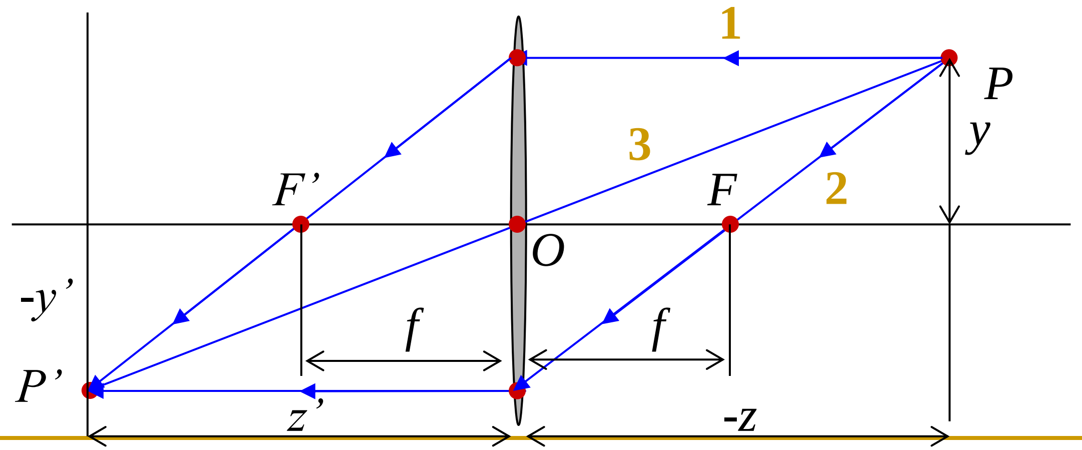
- Incident light rays parallel to the optical axis emerge on the other side and cross the optical axis at a distance f (called *focal length*) from the lens center.
- Points F and F' located at distance f from lens center are called *focal points* of the lens.



Camera with Lenses

Thin Lenses (properties):

1. Entering light rays parallel to the optical axis cross the optical axis on the other side at the focal point *F'*.
2. Entering light rays coming from the focal point *F* emerge parallel to the optical axis.
3. Entering light rays at the optical center *O* is not refracted
4. All rays emerging from *P* meet at *P'*



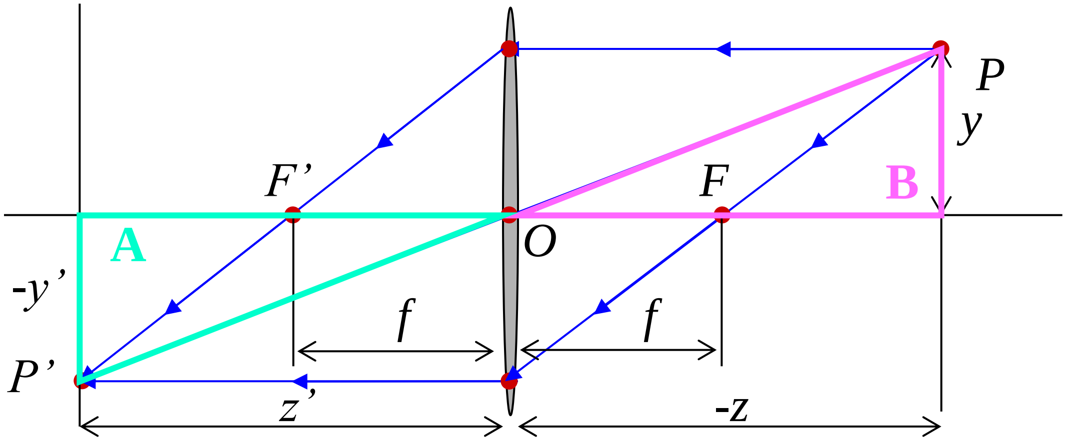
Camera with Lenses

Thin Lenses (properties):

Note that the triangles **A** and **B** are similar. Thus

$$\frac{y'}{y} = \frac{z'}{z} \Rightarrow y' = z' \frac{y}{z}$$

which is identical to the pinhole equation (if we replace *z'* by *f'*)!!!!!!



Camera with Lenses

Thin Lenses (properties):

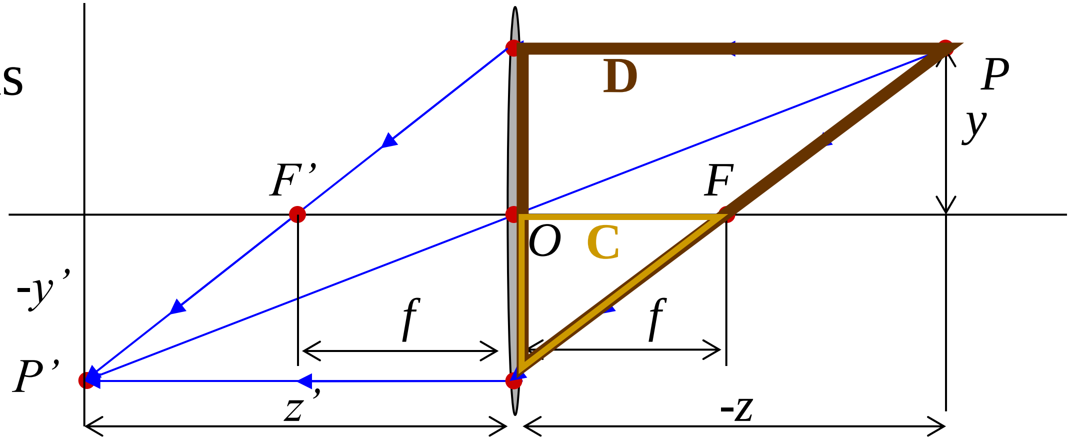
From the previous slide $\dfrac{y'}{y} = \dfrac{z'}{z}$

Considering the triangles **C** and **D** we get $\dfrac{-z}{f} = \dfrac{y - y'}{-y'}$

Combining both equations yields

$$\boxed{\frac{1}{z'} - \frac{1}{z} = \frac{1}{f}}$$

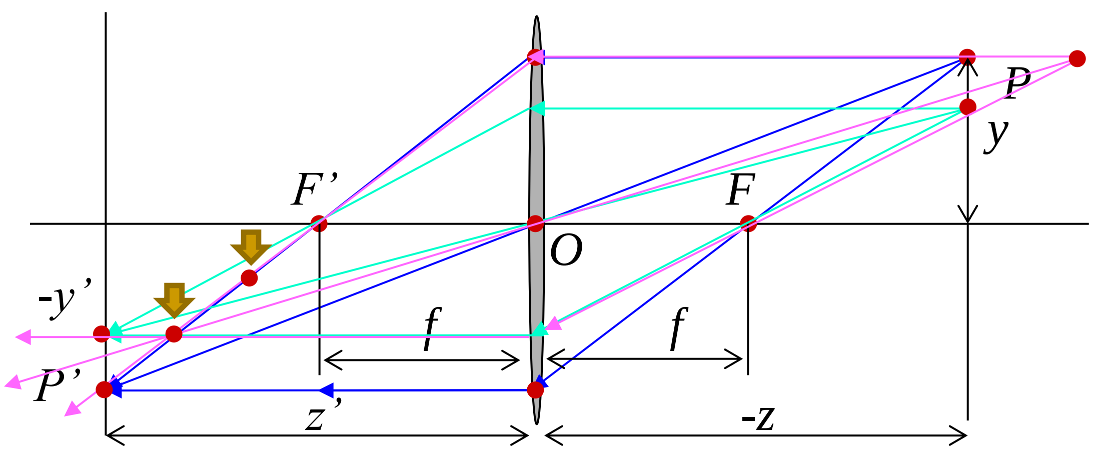
thin lens equation



Camera with Lenses

Thin Lenses (remarks)

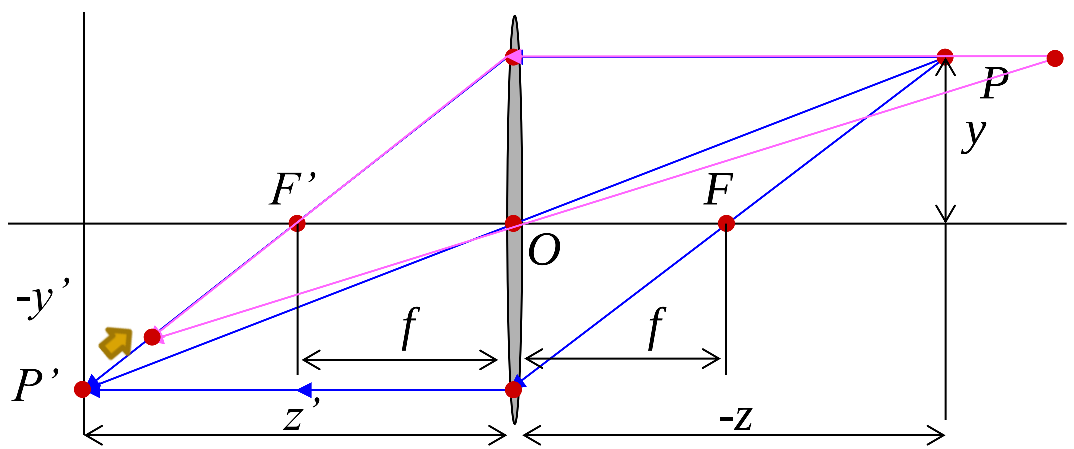
- image plane must be at a fixed distance z' to be in sharp focus.
- Points at different depths do not focus on the same plane.



Camera with Lenses

Thin Lenses (remarks)

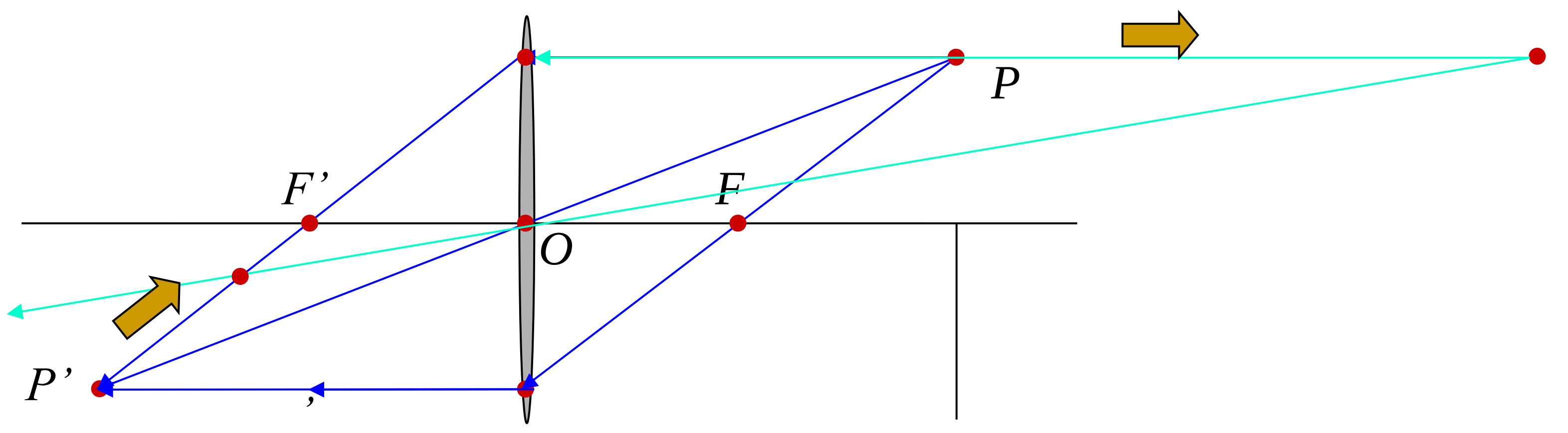
- image plane must be at a fixed distance z' to be in sharp focus.
- Points at different depths do not focus on the same plane.



Camera with Lenses

Thin Lenses (remarks)

- Point where emerging rays meet moves toward the focus as we go farther from the lens.
- the focal length *f* is the distance between the center of the lens and the plane where objects at $z \rightarrow \infty$ focus.



Camera with Lenses

Thin Lenses (remarks)

- *depth of field* or *depth of focus* is the range of distances in which objects are in acceptable focus.

Camera with Lenses

Thin Lenses (remarks)

- *depth of field* or *depth of focus* is the range of distances in which objects are in acceptable focus.

Camera with Lenses

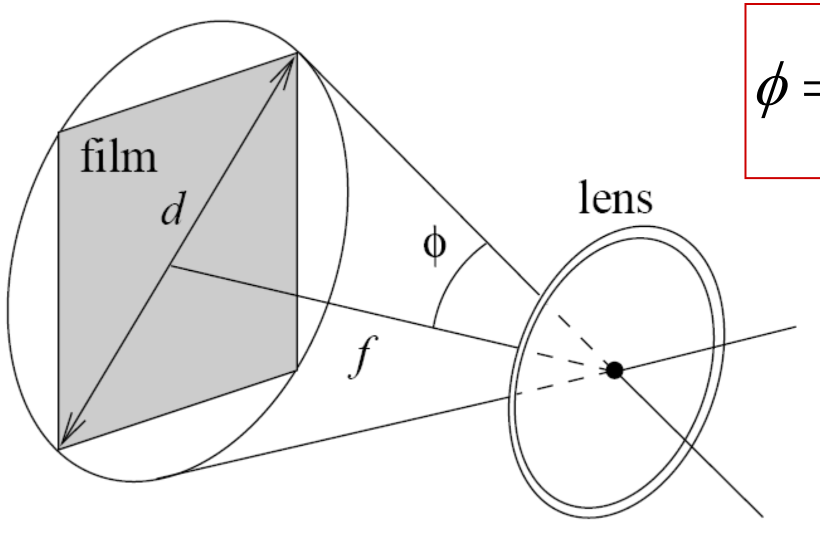
Thin Lenses (remarks)

- *depth of field* or *depth of focus* is the range of distances in which objects are in acceptable focus.

Camera with Lenses

Thin Lenses (remarks)

- *field of view* (2∅) of a camera is the portion of the scene space that actually projects onto the retina of the camera.

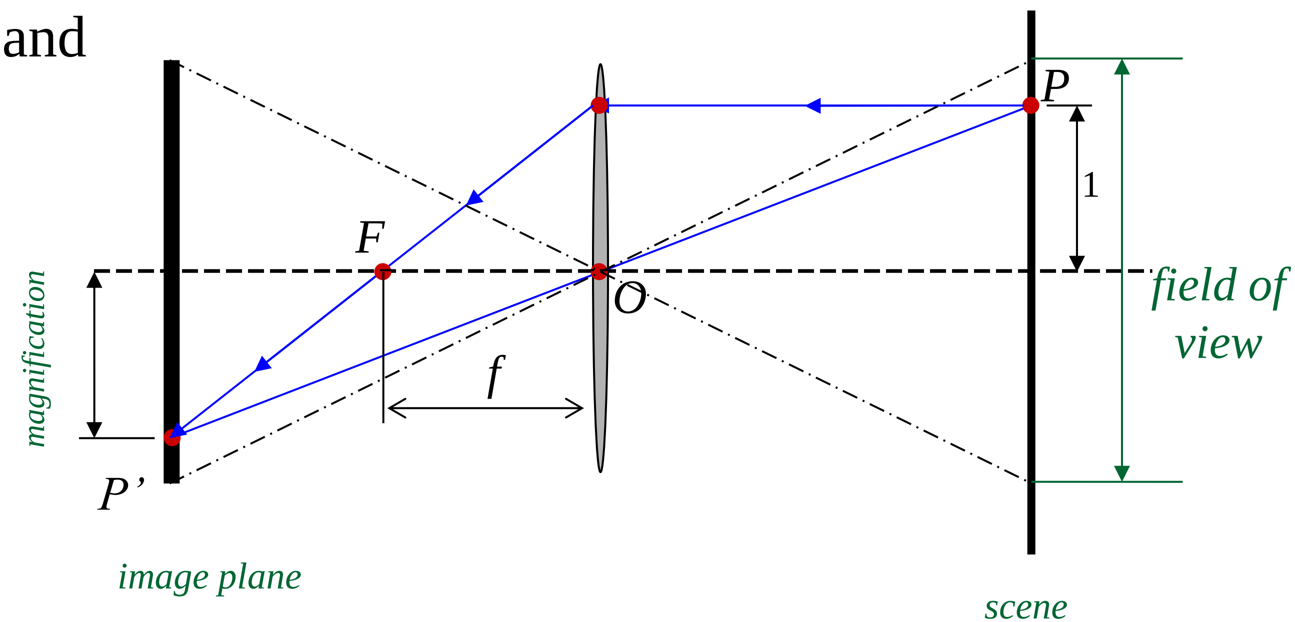


$$\phi = \arctan \frac{d}{2f}$$

Camera with Lenses

Relation between

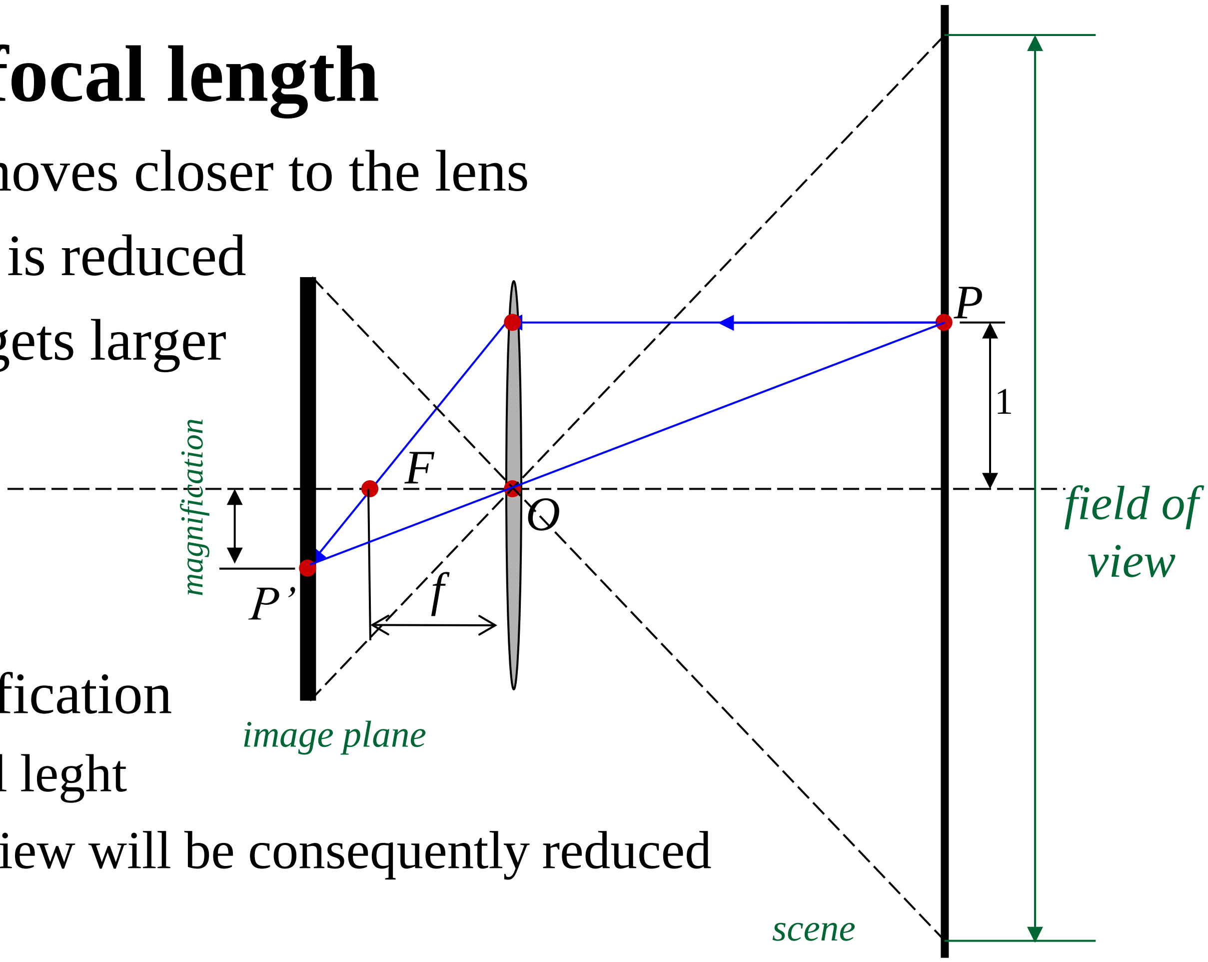
- focal length
- magnification, and
- field of view.



Camera with Lenses

By reducing the focal length

- The image plane moves closer to the lens
- The magnification is reduced
- The field of view gets larger

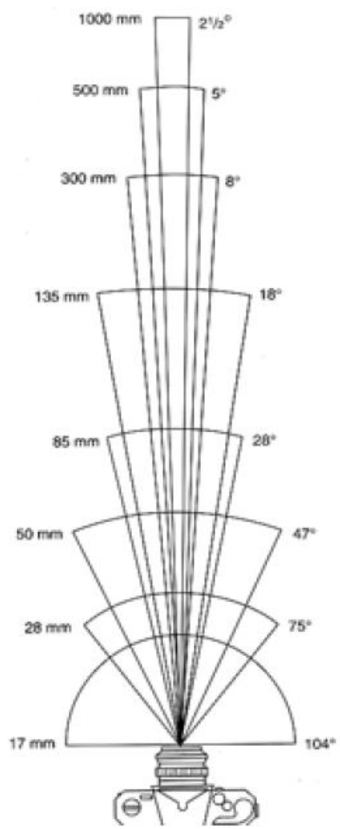


Therefore

- To increase magnification
  - increase the focal leght
  - and the field of view will be consequently reduced
- and vice-versa.

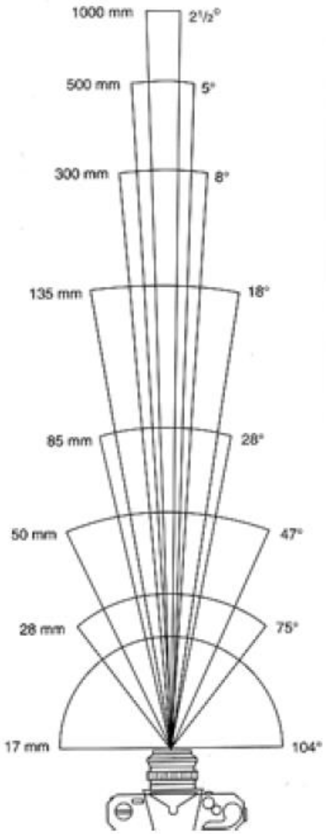
Camera with Lenses

Field of View/Focal Length



Camera with Lenses

Field of View/Focal Length



Camera with Lenses

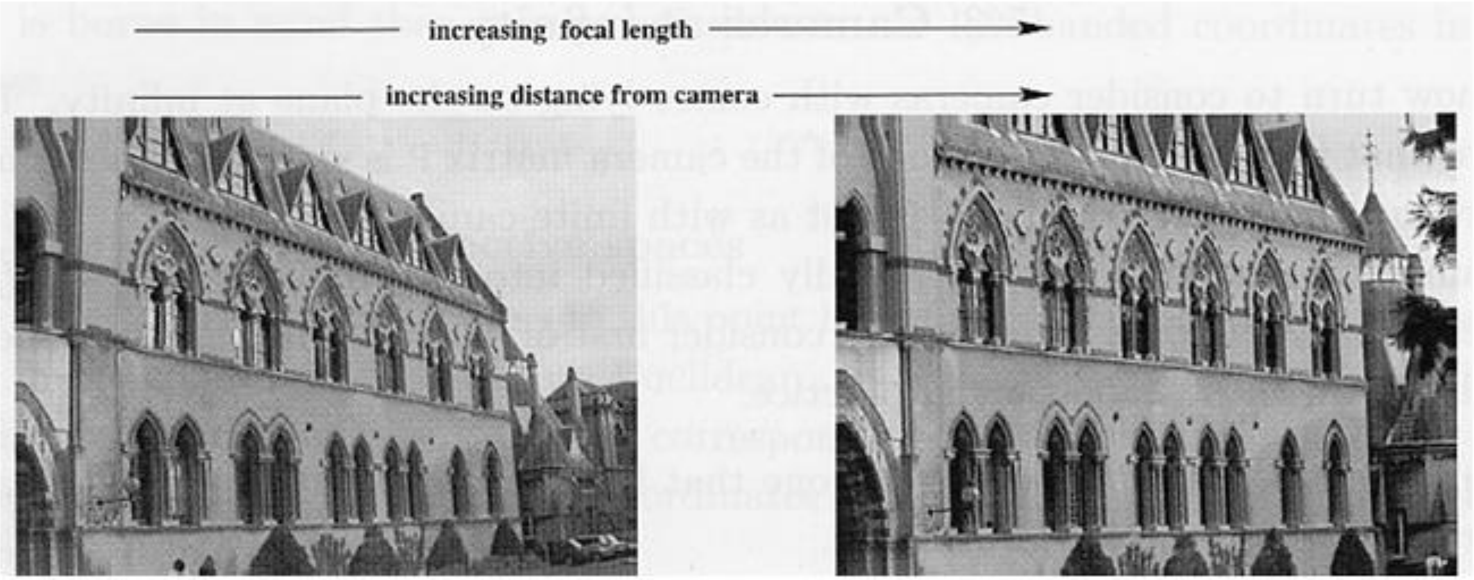
Field of View/Focal Length

Large FOV
Short focal length
Camera close to car

Small FOV
Large focal length
Camera far from the car

Camera with Lenses

Field of View/Focal Length



From Zisserman & Hartley

Camera with Lenses

Large Focal Length compresses depth

400 mm 200 mm 100 mm 50 mm 28 mm 17 mm

Aberrations

Thin Lens Model

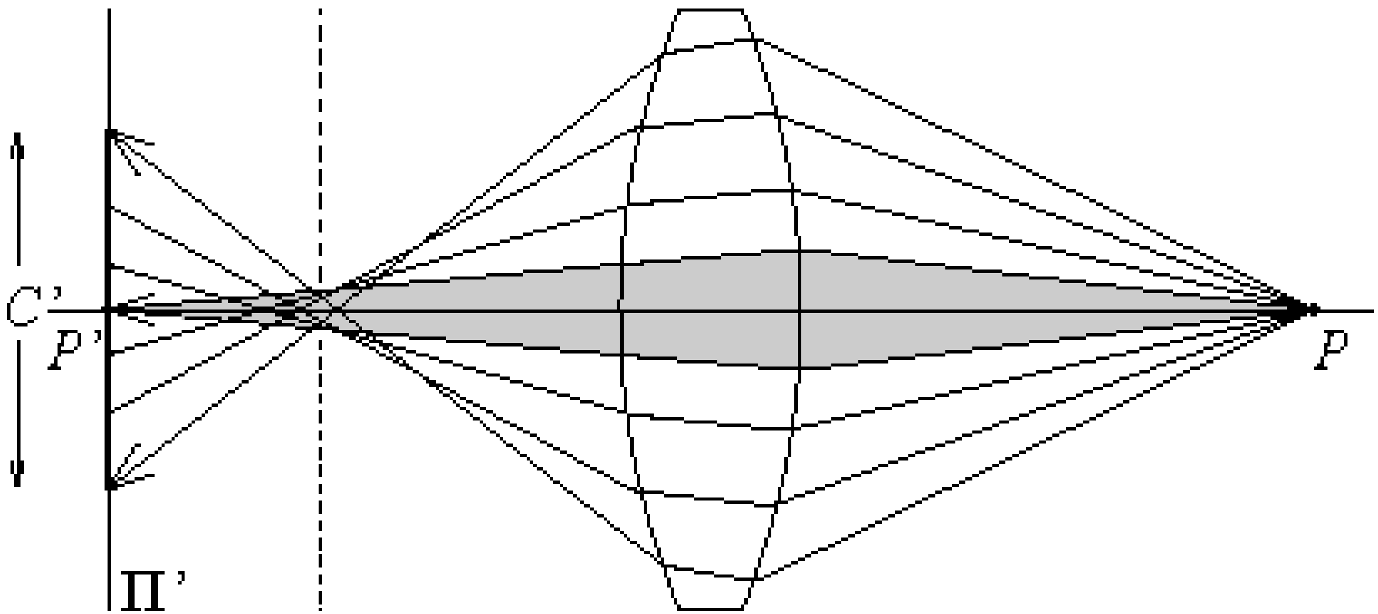
- bases on 3 assumptions

1. all rays from a point are focused onto 1 image point
2. all image points in a single plane
3. magnification is constant

deviations from this ideal are *aberrations*

Aberrations

Real (thick) lenses suffer from spherical aberrations - a point in space does not project on a single point on the image plane.



Aberrations

Geometrical:

- Distortion: magnification/focal length different for different angles of inclination → straight lines curve around the image center

pin cushion

barrel

Aberrations

Chromatic: refractive index function of wavelength

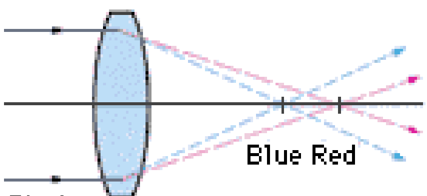


Fig.1
Axial chromatic aderration

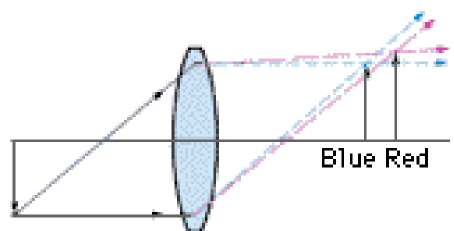
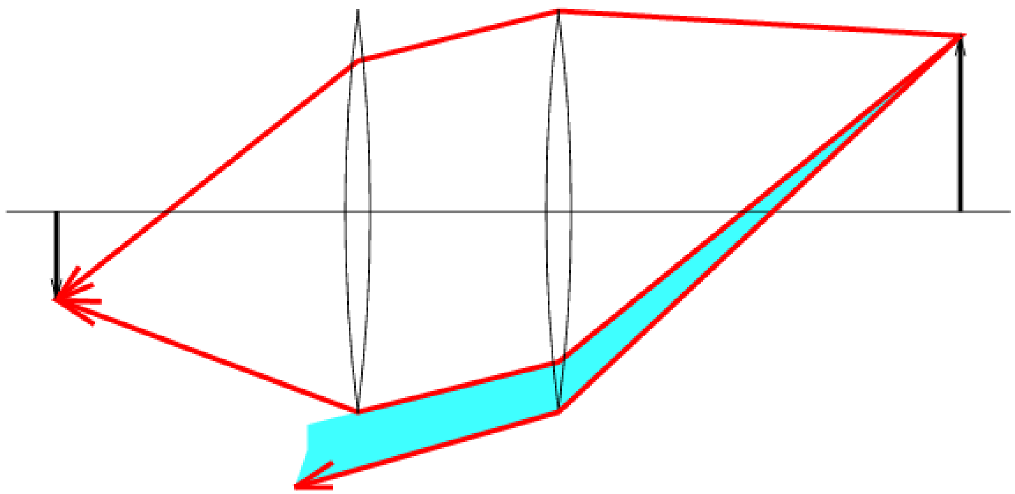


Fig.2
Magnification chromatic aderration

The image is blurred and appears colored at the fringe.

Aberrations

Aberrations can be minimized by aligning several simple lenses with well-chosen shapes and refraction indexes, separated by appropriate stops.



(*Vignetting*) brightness drops in the image periphery

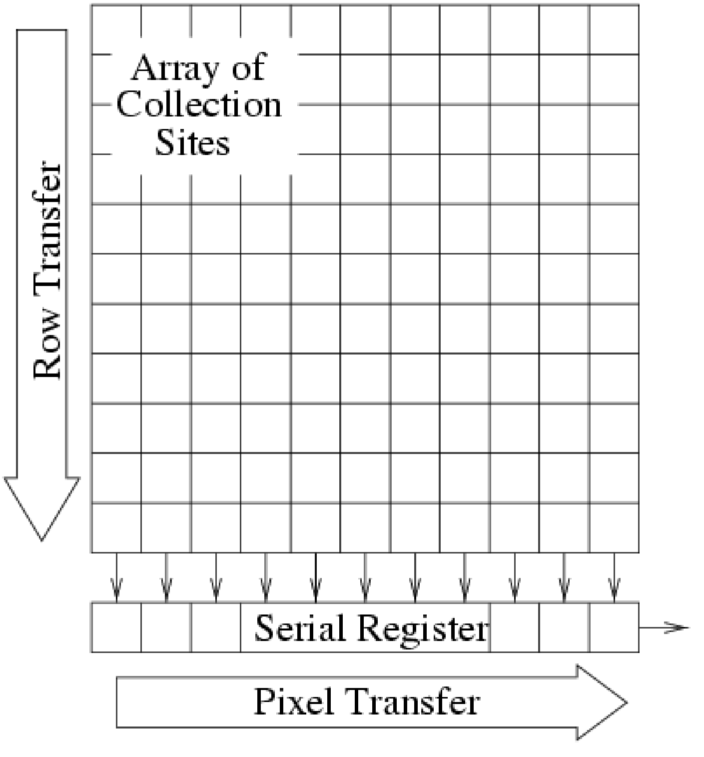
Sensing

Photographic Film

The first photograph on record, *la table servie*, obtained by Nicéphore Niepce (1822)

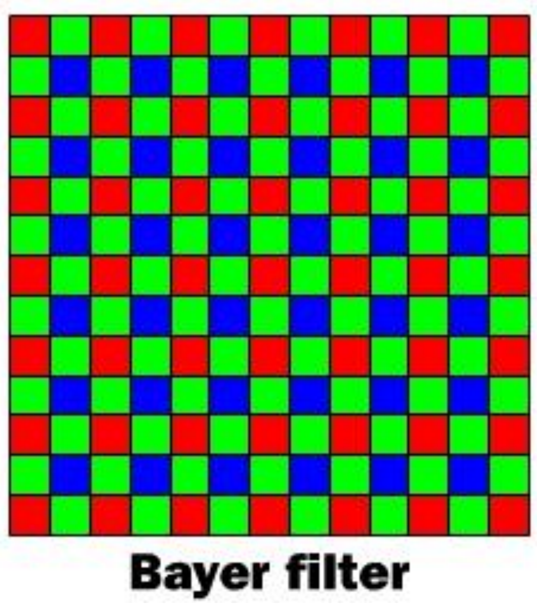
Sensing

CCD (*Charged Coupled Devices*)



Sensing

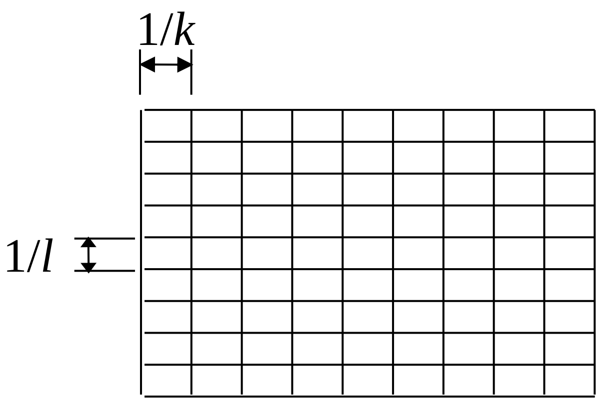
CCD (*Charged Coupled Devices*)



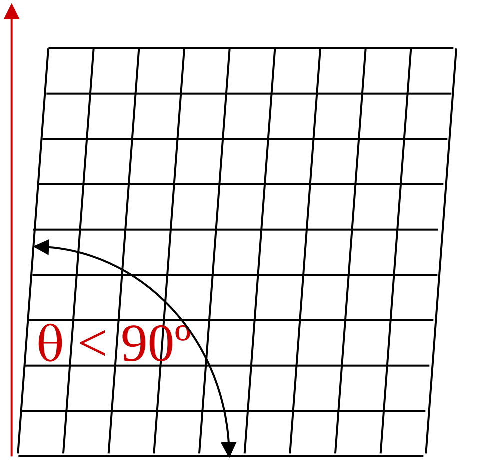
Sensing

CCD (*Charged Coupled Devices*)

imperfections in the sensor matrix



aspect ratio ≠ 1



skew

Next Topic

Geometric

Camera

Models